

LUMINOSITY AND STELLAR MASS FUNCTIONS OF LOCAL STAR-FORMING GALAXIES

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ABSTRACT

We present the optical and near-infrared luminosity and mass functions of the local star-forming galaxies in the Universidad Complutense de Madrid (UCM) Survey. A bivariate method that explicitly deals with the H α selection of the survey is used when estimating these functions. Total stellar masses have been calculated on a galaxy-by-galaxy basis taking into account differences in star formation histories. The main difference between the luminosity distributions of the UCM sample and the luminosity functions of the local galaxy population is a lower normalization (ϕ^*), indicating a lower global volume density of UCM galaxies. The typical near-infrared luminosity (L^*) of local star-forming galaxies is fainter than that of normal galaxies. This is a direct consequence of the lower stellar masses of our objects. However, at optical wavelengths (B and r), the luminosity enhancement arising from the young stars leads to M^* values that are similar to those of normal galaxies. The fraction of the total optical and near-infrared luminosity density in the local universe associated with star-forming galaxies is 10%–20%. Fitting the total stellar mass function using a Schechter parameterization, we obtain $\alpha = -1.15 \pm 0.15$, $\log M^* = 10.82 \pm 0.17 \mathcal{M}_\odot$, and $\log \phi^* = -3.04 \pm 0.20 \text{ Mpc}^{-3}$. This gives an integrated total stellar mass density of $10^{7.83 \pm 0.07} \mathcal{M}_\odot \text{ Mpc}^{-3}$ in local star-forming galaxies ($H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.3$, and $\Lambda = 0.7$). The volume-averaged burst strength of the UCM galaxies is $b = 0.04 \pm 0.01$, defined as the ratio of the mass density of stars formed in recent bursts (with an age of $<10 \text{ Myr}$) to the total stellar mass density in UCM galaxies. Finally, we derive that in the local universe, $13\% \pm 3\%$ of the total baryon mass density in the form of stars is associated with star-forming galaxies.

Subject headings: galaxies: luminosity function, mass function — galaxies: starburst — infrared: galaxies

1. INTRODUCTION

The star formation activity is a topic of growing interest as we extend the study of the galaxy population to higher and higher redshifts. Part of this interest is due to the fact that many distant objects show an intense starbursting activity (see, e.g., Ellis 1997; Ferguson, Dickinson, & Williams 2000 and references therein). One of the issues that is being addressed is the characterization of the global properties of the galaxy population as a function of look-back time. One of the most important of these properties is the comoving star formation rate (SFR) density of the universe (see, e.g., Haarsma et al. 2000; Somerville, Primack, & Faber 2001; Rowan-Robinson 2001; Lanzetta et al. 2002). Another issue of cosmological interest is the luminosity evolution of the galaxies along the Hubble time. One way to study this evolution is through the measurement of the number density of galaxies of a given luminosity as a function of redshift, i.e., the time evolution of the luminosity function (LF). A considerable amount of effort has been devoted to the determination of the LF at a variety of redshifts and spectral ranges (among others, Efstathiou, Ellis, & Peterson 1988; Steidel et al. 1999; Loveday 2000; Kochanek et al. 2001; Cole et al. 2001; Norberg et al. 2002).

Mass is even more fundamental than luminosity among the parameters governing the formation and evolution of galaxies. Indeed, it may be possible to distinguish between hierarchical

and single collapse models of galaxy formation using the mass of the observed galactic structures and the history of their assembly as the differentiating parameters (see Aragón-Salamanca, Baugh, & Kauffmann 1998; Baugh et al. 1998; Fukugita, Hogan, & Peebles 1998; Kauffmann et al. 1999). Therefore, it is extremely important to characterize the stellar and total masses of galaxies at all redshifts and the number density of objects of a given mass, i.e., the stellar mass function (SMF).

In this Letter, we have used the multiwavelength data set for the Universidad Complutense de Madrid (UCM) Survey of emission-line galaxies (ELGs; Zamorano et al. 1994, 1996) to estimate the LFs and SMF of a complete sample of local star-forming galaxies in the optical and near-infrared (NIR). Given that the UCM Survey galaxies were selected by their active star formation, our results are directly comparable to the ones achieved for samples of star-forming galaxies at high redshift, although one must be aware of the differences on the selection techniques. Unless otherwise indicated, throughout this Letter we use a cosmology with $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.3$, and $\Lambda = 0.7$.

2. THE SAMPLE

The UCM sample contains 191 local star-forming galaxies at redshifts lower than 0.045, with an average $\langle z \rangle = 0.026$. These objects were selected from an objective-prism survey carried out with the Schmidt Telescope at Calar Alto Observatory (Almería, Spain) and centered at the wavelength of the H α nebular emission (Zamorano et al. 1994, 1996). Comparisons with other samples of star-forming galaxies selected using a variety of techniques reveal that the UCM sample is representative of the local population of star-forming galaxies (Gallego et al. 1997; Salzer et al. 2001; Salzer 1989; Treyer et al. 1998). Indeed, the SFR density of the local universe derived from the UCM sample is reasonably consistent with that de-

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rived from other samples (see, e.g., Treyer et al. 1998; Serjeant, Gruppioni, & Oliver 2002).

Optical spectroscopy is available in Gallego et al. (1996), and photometry in the Gunn r and Johnson B filters can be found in Vitores et al. (1996) and Pérez-González et al. (2000), respectively. NIR data (J and K_s bands) were presented in Gil de Paz et al. (2000) and Pérez-González et al. (2003a). An H α imaging study has also been carried out recently (Pérez-González et al. 2003c). For a complete compendium of the spectroscopic and photometric properties of the sample, the reader can refer to Pérez-González et al. (2003a and references therein).⁵

In this Letter, we present LFs in the four available optical and NIR bands: Johnson B , Gunn r , J , and K_s . Out of the original 191 galaxies, 15 were classified as active galactic nuclei by Gallego et al. (1996) and have been excluded. A further 11 galaxies have no data for the line+continuum magnitudes (see § 3). Thus, the sample used in this Letter is composed of 165 objects. The total numbers of objects with available photometry in each band are 165 in B , 142 in r , 143 in J , and 164 in K_s .

The luminosities have been corrected for Galactic extinction using the maps of Schlegel, Finkbeiner, & Davis (1998) and the extinction curve in Cardelli, Clayton, & Mathis (1989). We have also applied k -corrections from Fioc & Rocca-Volmerange (1999) for BJK_s and Fukugita, Shimasaku, & Ichikawa (1995) for Gunn r , taking into account the morphological types of the UCM galaxies (Pérez-González et al. 2001). The k -corrections applied are small because of the low redshifts of our galaxies ($z < 0.045$).

Total stellar masses for nearly all the UCM galaxies (156 objects) were calculated in Pérez-González et al. (2003b) using a complete set of stellar population synthesis models to reproduce the broadband and emission-line spectral features in the optical and NIR. Taking into account different star formation histories, the technique calculated mass-to-light ratios in the K_s band (M/L_{K_s}) on a galaxy-by-galaxy basis. This Letter uses the results on masses and burst strengths (ratio of the mass of the stars younger than 10 Myr and the total stellar mass) that were calculated in Pérez-González et al. (2003b), assuming an instantaneous burst of star formation with a Salpeter (1955) initial mass function ($M_{\text{low}} = 0.1 M_{\odot}$ and $M_{\text{up}} = 100 M_{\odot}$) occurring on a “normal” spiral galaxy. We used the stellar evolution synthesis library of G. Bruzual & S. Charlot (1999, private communication). The attenuation of the burst luminosity was modeled with the recipe given in Charlot & Fall (2000). The stellar masses obtained using the alternative extinction recipes considered in Pérez-González et al. (2003b) were statistically very similar. Thus, the choice of extinction recipe has negligible effect on the results presented here.

3. ESTIMATING THE LFs AND SMFs

The selection of the UCM Survey galaxies depends primarily on the H α line flux and its contrast against the continuum (Gallego et al. 1995). This contrast may be measured by a line+continuum magnitude m_{L+C} (Salzer 1989). In the present work, we are concerned with the calculation of the luminosity and mass functions of the sample in broadband filters far away from the passband where the selection took place. Therefore, a proper way of estimating these functions is using a bivariate luminosity function (BLF), $\phi(M_{L+C}, M_n)$, which allows for sample selection in one particular magnitude (m_{L+C}) and may be integrated over this magnitude to obtain the LF in the re-

quired filter, $\phi(M_n)$. The method is analogous to the one described in Loveday (2000). It is an extension of the stepwise maximum likelihood technique presented in Efstathiou et al. (1988), which properly handles the effects of not observing a small fraction of the entire sample in the band where we are estimating the LF (Sodre & Lahav 1993).

All the LF data points have been fitted to Schechter (1976) functions, taking the observational errors into account. The uncertainties in the fitted parameters have been estimated considering uncorrelated random variations of the LF points following a Gaussian distribution with its width set by the errors of the data points. We calculate the errors in α , M^* , and ϕ^* by repeating the fit for each set of points with small random variations.

The bivariate method of estimating LFs has also been applied to the calculation of the total stellar mass and burst mass functions of the UCM sample, i.e., the volume density of local star-forming galaxies and local starbursts as a function of mass. The use of this procedure when estimating the SMF relies on principles similar to those of the LF calculations. It uses a bivariate function $\phi(M_{L+C}, \mathcal{M}_*)$ defined as the number density of galaxies of a given M_{L+C} and \mathcal{M} . Note that the SMF is often obtained by multiplying the K_s -band LF by a constant \mathcal{M}/L_{K_s} . However, several authors (Brinchmann & Ellis 2000; Bell & de Jong 2001; Papovich, Dickinson, & Ferguson 2001; Pérez-González et al. 2003b) have suggested that there could be sizable galaxy-to-galaxy variations in \mathcal{M}/L_{K_s} because of differences in star formation histories. Therefore, it seems safer to estimate the SMF using individually estimated \mathcal{M}/L_{K_s} ratios for each galaxy, as we do here.

4. RESULTS

4.1. Luminosity Functions

In order to test the BLF method, we used it to recalculate the H α LF of the UCM sample. The results are almost identical to the ones achieved with the V/V_{max} method (Schmidt 1968; Huchra & Sargent 1973) used by Gallego et al. (1995) and Pérez-González et al. (2003c). This adds confidence to our results.

Figure 1 shows the LFs of the UCM sample in $BrJK_s$. For comparison, we also plot the LFs of the local galaxy population obtained from different surveys. The dotted line in the left panel of Figure 1 shows the B -band LF of the Two-Degree Field Galaxy Redshift Survey (2dFGRS; Norberg et al. 2002). These galaxies have redshifts up to ≈ 0.2 , with a modal z of 0.05. The main difference between the 2dFGRS LF and the UCM LF is a lower number density normalization ($\phi_{\text{UCM}}^*/\phi_{\text{2dFGRS}}^* = 0.19$). This is not a surprise, since not all the galaxies in the 2dFGRS emit in H α . The r -band LF (Fig. 1, *second panel*) is compared to the LFs derived from the Las Campanas Redshift Survey (*dash-dotted line*; $\langle z \rangle \approx 0.1$; Lin et al. 1996) and the Century Survey (*dashed line*; $z \leq 0.15$; Geller et al. 1997).⁶ The comparison reveals again a lower number density of UCM galaxies ($\phi_{\text{UCM}}^*/\phi_{\text{LCRS}}^* = 0.15$ and $\phi_{\text{UCM}}^*/\phi_{\text{CS}}^* = 0.11$). The J - and K_s -band LFs are compared with those of the 2dFGRS (Cole et al. 2001; dotted lines in the last two panels of Fig. 1) and the Two Micron All Sky Survey (2MASS; *dashed lines*; Jarrett et al. 2000). The J -band 2MASS LF comes from Balogh et al. (2001), with the global normalization of Cole et al. (2001). The K_s 2MASS LF was published by Kochanek et al. (2001). In both bands a nor-

⁵ See http://www.ucm.es/info/Astrof/UCM_Survey/survey.html.

⁶ These LFs have been transformed into the r band using $r - R_c = 0.36$, typical of spiral galaxies (Fukugita et al. 1995). Note also that these LFs have been obtained using different Ω_m and Λ values, but given the moderate redshift of the samples, we have not made any correction in order to match the cosmologies.

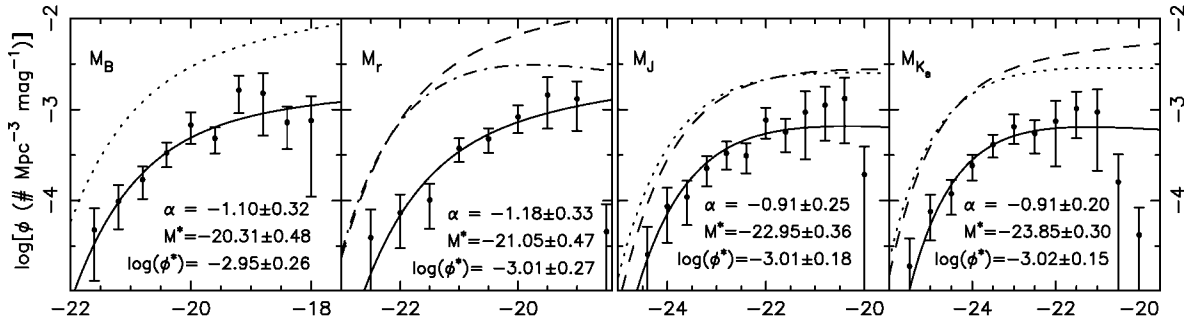


FIG. 1.—LFs for the UCM sample in the Johnson B , Gunn r , J , and K_s bands. The Schechter fit parameters are given inside each panel. The units of ϕ^* are Mpc^{-3} . The LFs of several samples of normal galaxies have also been plotted for comparison (see text for details).

malization offset is observed again: $\phi_{\text{UCM}}^*/\phi_{\text{2dFGRS}}^* = 0.27$ in J and $\phi_{\text{UCM}}^*/\phi_{\text{2dFGRS}}^* = 0.26$ and $\phi_{\text{UCM}}^*/\phi_{\text{2MASS}}^* = 0.24$ in K_s .

The shapes of the luminosity distributions of the UCM sample are not very different from those of the global population of galaxies in the local universe. However, since the UCM galaxies have typically higher star formation activity than normal quiescent spiral galaxies (Pérez-González et al. 2003b), a lower number density is found. The ratios of the *integrated* luminosity densities for the local star-forming objects in the UCM Survey and for the global population of galaxies are 0.15 ± 0.05 , 0.11 ± 0.04 , 0.23 ± 0.04 , and 0.18 ± 0.03 in B , r , J , and K_s . Note that the local galaxy population LFs in the B , J , and K_s bands have been derived in a homogeneous way from the 2dFGRS. Remarkably, these luminosity density ratios are comparable at all wavelengths and very similar to the ratio of the number of enhanced star-forming galaxies to the total (Zamorano et al. 1996). The luminosity density ratios do not depend strongly on luminosity. Moreover, these ratios are a factor of ~ 2 higher than the nearby galaxy-pair fraction, estimated to be 6%–10% by Keel & van Soest (1992). This might

suggest that a significant fraction of the star formation activity in the local universe is driven by minor mergers, in which the smaller infalling object is not always detectable.

In the NIR, the UCM galaxies yield fainter M^* values (by 0.4 mag) than the normal galaxy samples. This is directly related to the lower typical stellar masses found for the local star-forming objects (Pérez-González et al. 2003b): the J and K_s luminosities are strongly correlated with the total stellar mass while being less influenced by recent star formation. However, the enhanced star formation is responsible for the UCM Survey presenting M^* values similar to those of normal galaxies at optical wavelengths despite having smaller stellar masses.

4.2. Mass Functions

Figure 2 shows the total SMF (*filled circles*) and burst mass function (*stars*) for the UCM galaxies calculated as described in § 3. Schechter function fits (*solid and dotted lines*, respectively) are also shown. In addition, we have calculated the SMF multiplying the K_s -band LF by a constant $M/L_{K_s} = 0.78$ (in solar units), the average mass-to-light ratio used in Pérez-González et al. (2003b) for the evolved stellar populations within the UCM galaxies (*open circles*). At high masses, this simple estimate of the SMF coincides with the one obtained using individual M/L_{K_s} values. However, large differences appear for low-mass galaxies: these objects harbor the most intense bursts (Pérez-González et al. 2003b), which have a major influence on the M/L_{K_s} ratios. The errors introduced by using a constant M/L_{K_s} are expected to be much larger at high z , where the burst strengths are higher.

A Schechter function seems to provide a reasonable fit to the total SMF. The typical stellar mass (M_*) of the local star-forming galaxies in the UCM sample is a factor of ~ 2 smaller than that of the local galaxy population (Cole et al. 2001). This is directly related to the fainter NIR M^* found for the UCM galaxies. The faint end slope (α) of our SMF and the one published in Cole et al. (2001) are virtually identical.

We have integrated the total SMF in Figure 2 to obtain the total stellar mass density in local star-forming galaxies, $\rho_{\text{stars}}^{\text{ELG}}(z=0) = 10^{7.83 \pm 0.07} \text{M}_{\odot} \text{Mpc}^{-3}$. This corresponds to $13\% \pm 3\%$ of the baryon mass density in the form of stars and their remnants estimated by Persic & Salucci (1992), Fukugita et al. (1998), and Cole et al. (2001) for the local universe.

Integrating the burst SMF allows us to calculate the volume-averaged burst strength b of these star-forming galaxies, defined as the ratio of the burst mass density to the total stellar mass density. We find $b(z=0) = 0.04 \pm 0.01$. This means that $\sim 4\%$ of the total stellar mass in local star-forming galaxies corresponds to stars younger than ≈ 10 Myr (Pérez-González

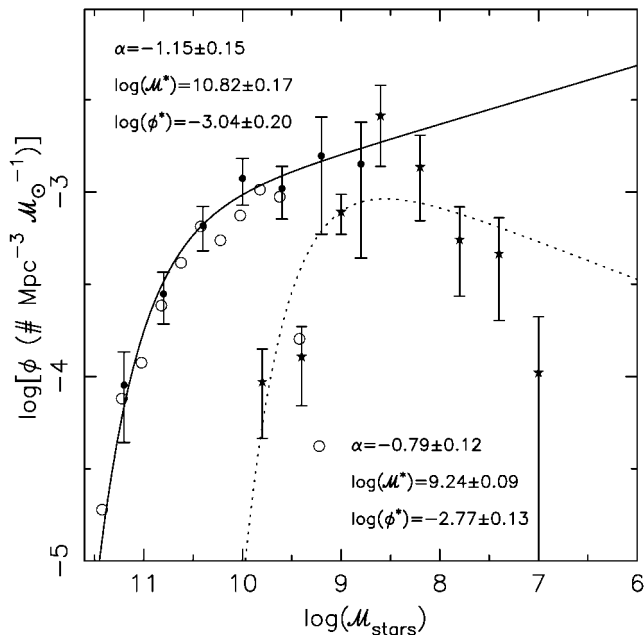


FIG. 2.—Total SMF (*filled circles and solid line*) and burst mass function (*stars and dotted line*) for the UCM sample. Open symbols show the mass function calculated by multiplying the K_s -band LF by a constant $M/L_{K_s} = 0.78$. The Schechter fit parameters are given for the total masses (*top left corner*) and burst masses (*bottom right corner*). Masses are in solar units and ϕ^* in Mpc^{-3} .

et al. 2003b). Note that the galaxies within the UCM Survey have $\text{EW}(\text{H}\alpha) > 20 \text{ \AA}$ (Gallego et al. 1995), so this value must be considered as a lower limit to the relative fraction of young stars in our local universe.

It is interesting to compare our measure of $\rho_{*}^{\text{ELG}}(z = 0)$ with high-redshift estimates. Our value is 1.6 times lower than the comoving stellar mass density in spiral galaxies at $0.4 < z < 1$ (Brinchmann & Ellis 2000). Also, when compared with the $z > 0$ galaxy samples presented in Dickinson et al. (2002), our results point toward a decline in ρ_{*}^{ELG} from $z \sim 1$ to $z = 0$. This is similar to the behavior observed for the SFR density. One should be cautious when making comparisons with $z > 1$, since the high- z samples are dominated by intense star formation and may present selection biases at least as important as the ones in our sample, leading to an underestimate of the global ρ_{*} .

5. SUMMARY AND CONCLUSIONS

In this Letter, we have presented the luminosity and mass functions of the local star-forming galaxies in the UCM Survey. Given that the UCM galaxies were selected by their active star formation, our results are directly comparable to those of high-redshift star-forming galaxies. In estimating these functions, we have accounted for the $\text{H}\alpha$ selection of our survey and calculated stellar masses on a galaxy-by-galaxy basis.

The main results of our study are as follows. (1) The LFs of the UCM Survey galaxies in the optical and NIR have lower normalizations than the LFs of the global population of galaxies, indicating a lower number density. This is not surprising, since the UCM galaxies have significantly higher star formation activity than normal quiescent galaxies and galaxies without star

formation are not present in the sample. (2) In the NIR, UCM galaxies have fainter characteristic magnitudes (M^{*}) than normal galaxies. This is a direct consequence of the lower typical stellar masses of our objects. However, the optical M^{*} values of the UCM galaxies are similar to those of normal galaxies, suggesting that the enhanced star formation has boosted up their optical luminosities. (3) The fraction of the total luminosity density in the local universe associated with star-forming galaxies is 0.15 ± 0.05 , 0.11 ± 0.04 , 0.23 ± 0.04 , and 0.18 ± 0.03 in B , r , J , and K_s . Remarkably, these luminosity fractions are comparable at all wavelengths and do not depend strongly on luminosity. This may be due to selection effects shared by all magnitude (and surface brightness) limited surveys. (4) If we fit the total SMF using a Schechter parameterization, we obtain $\alpha = -1.15 \pm 0.15$, $\log \mathcal{M}^{*} = 10.82 \pm 0.17 \mathcal{M}_{\odot}$, and $\log \phi^{*} = -3.04 \pm 0.20 \text{ Mpc}^{-3}$. This gives an integrated total stellar mass density in star-forming galaxies in the local universe of $10^{7.83 \pm 0.07} \mathcal{M}_{\odot} \text{ Mpc}^{-3}$. (5) The volume-averaged burst strength of the UCM galaxies is $b = 0.04 \pm 0.01$, defined as the ratio of the mass density of stars formed in recent bursts (with an age of $< 10 \text{ Myr}$) to the total stellar mass density in UCM galaxies. (6) We estimate that $13\% \pm 3\%$ of the total baryon mass density in the form of stars is associated with star-forming galaxies in the local universe.

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